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NEGATIVE IMPACT OF AIR POLLUTION ON PRODUCTIVITY: PREVIOUS DANISH FINDINGS REPEATED IN NEW SWEDISH TEST ROOM

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ABSTRACT

The objective of this study was to test a new office space where the environmental conditions could be well controlled – a "field laboratory", located at Mid Sweden University in Östersund. To test the laboratory, the same experiment that had been carried out earlier at the Technical University of Denmark (DTU) was repeated. A further objective was to test whether the earlier results from DTU showing a negative impact of increased indoor air pollution on perceived air quality, Sick Building Syndrome (SBS) symptoms and performance could be repeated. In the experiment, the air pollution was altered in the office by introducing or removing a pollution source, a 20-year-old used carpet, used earlier in DTU's study. All other environmental parameters were kept unchanged. Thirty female subjects performed simulated office work in the office under two exposure conditions. They also assessed perceived air quality and intensity of SBS symptoms several times during exposure. The exposure lasted 4.6 h in the afternoon. The subjects could not see whether the source was present or not and remained thermally neutral by adjusting their clothing. When the pollution source was absent, there was a lower percentage dissatisfied with the air quality ($P<0.02$). Increased intensity of "dizziness" ($P<0.03$) and "difficulty in thinking clearly" ($P<0.04$) were significantly associated with the exposure during which the pollution source was present in the office. Also at this exposure subjects typed less ($P<0.02$) and made more errors when adding numbers ($P<0.02$). In conclusion, the office serving as a field laboratory operates reliably and the results obtained in the present study support the earlier findings of DTU.

KEYWORDS: Office work; Perceived air quality; Performance; SBS; Source control

INTRODUCTION

To study experimentally how different parameters of the indoor environment influence comfort, health and productivity of humans, a test room was set up at the Technical University of Denmark (DTU) in a normal office in which the indoor climate conditions can be controlled [1]. The idea behind this test room is to combine the controlled environment of a climate chamber with a natural office environment, i.e. normally furnished and with access to windows and daylight. The test room is called a "field laboratory". In the present study, a similar "field laboratory", in Sweden at Mid Sweden University in Östersund, was set up and tested. The aim was to investigate whether the negative effects of air pollution on human comfort, health and productivity obtained in the "field laboratory" at DTU in Denmark [1] could be repeated, if a similar methodology and the same pollution source were used, in another room in another part of Scandinavia, using different subjects.

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METHODS

Facilities

The office adapted into a field laboratory in this study was built in 1984, and has not been renovated since then. The floor area of the office is 65 m^2 and the volume 163 m^3 (height 2.5 m). There are two windows, one facing to the north and one facing to the north-west (Figure 1) with an opening surface of 7.15 m^2. The floor covering is made of linoleum. The walls are made of gypsum boards and are covered with wallpaper. The suspended ceiling is made of sound-absorbing plates made of mineral fibre. As all surface materials are 15 years old it was assumed that the primary emissions of pollutants in the office were at a very low level.

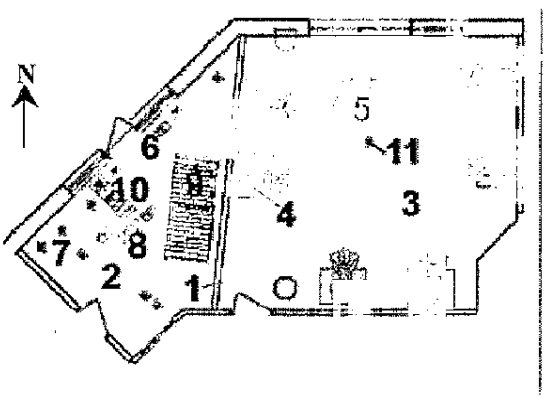

Figure 1. Layout of the new Swedish "field laboratory". 1- partition, 2- technical space, 3- space used by the subjects, 4- workstation, 5- wooden stair, 6- steam humidifier, 7- mixing fan, 8- electric oil heater, 9- rack for the pollution source, 10- axial fan, 11- location of indoor environment sensors

The room was divided into two spaces by means of a partition made of low-polluting steel frames and gypsum boards; both spaces had access to windows. The partition was 2 m high, so that the air could mix in the entire laboratory. At the same time, subjects exposed in one space could not see into the other space. Both spaces were accessible from adjacent rooms by separate doors. One space was equipped with six workstations, consisting of a desk, a chair, a computer (PC) and a desk lamp (Figure 1). Six subjects could be exposed in this space at a time. There was also a small wooden stair used for physical exercises during the experiments in this space. In the technical space (behind the partition), equipment for ventilating and conditioning the air was placed. The air was supplied by an axial fan mounted in the window and is conditioned by electric oil heaters and steam humidifiers. The temperature and humidity were controlled by PID-controllers with sensors placed in the middle of the occupied space. Small fans were placed in the technical space to ensure that the air was well mixed and that pollutants were uniformly distributed in the "field laboratory". As no traditional HVAC system was used, there was no risk of pollution by the ventilation system. In the technical space, steel racks were placed to accommodate the extra pollution source.

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Procedure

To test the "field laboratory" the study of Wargocki et al. [1] was repeated. Two conditions were tested: with an extra pollution source present or absent. The pollution source was the same as that used by Wargocki et al. [1], namely a 20-year-old used carpet taken from an office building with a history of SBS symptoms [2]. The total size of the carpet corresponded to the floor area of the entire "field laboratory" (65 m^2). The strips of carpet were stapled together back-to-back so that only the front surface was exposed to the air. They hung on racks behind the partition and were invisible to the subjects.

The operative temperature of 22°C, the relative humidity of 30%, the ventilation rate of 10 L/s per person (1.3 h^{-1}) and the air velocity of ≤0.15 m/s was kept constant all the time. The thermal conditions were chosen to suit a northern Scandinavian winter, this being the reason why they differed from the temperature of 24°C and the relative humidity of 50% used by Wargocki et al. [1]; the ventilation rate and air velocity were identical in both studies. Thirty female subjects, in groups of 6 at a time, were exposed in the office when the pollution source was present and absent in a repeated-measures design balanced for order of presentation. The subjects were 20 to 31 years old, did not smoke and were all students from Mid Sweden University; 28 of them completed all experiments. All subjects, except one who had hay fever, were non-atopic. The subjects were paid for participating at a fixed rate per hour and an extra bonus of 10% of the amount was offered salary depending on their performance, in order to increase their motivation.

The experiment took place during two succeeding weeks in April 1999. Before the experiment, the subjects received training in the performance tasks and they were all instructed on how to fill out the questionnaires on perceived air quality and SBS symptoms. Swedish versions of the questionnaires from the DTU study were used. The assessments of SBS symptoms were obtained by using visual-analogue scales (VAS) [3] in the questionnaires. Before entering the "field laboratory", the subjects assembled in an adjoining room. The experimenter then led them into the office. Immediately upon entering, they assessed the air quality, SBS symptoms and indoor climate. These assessments were thereafter repeated regularly during exposure, ca. every hour, and were always followed by a physical exercise - subjects walked over the wooden stairs to simulate physical activity in a normal office.

During the first part of the exposure, the subjects performed the following tasks: proof-reading (for 20 min), addition (for 20 min), creative thinking (for 25 min) and text typing (for 55 min). After a 10 min break, the second part of the exposure was started where the subjects performed the tasks again but in the following order: addition (for 20 min), text typing (for 55 min), proof-reading (for 20 min) and creative thinking (for 25 min). Addition and text typing tasks were similar to those used by Wargocki et al. [1]. The exposure lasted 4.6 h in the afternoon (starting at 1 p.m.). During the entire length of the exposures, the subjects were regularly encouraged to adjust their clothing, so that they felt neither too warm nor too cold. Following the exposure, the subjects returned to the well-ventilated room where they had assembled prior to exposure. After 3-5 min, they re-entered the office to re-assess the air quality. Finally, the subjects assessed the air quality outdoors. Air temperature, operative temperature, relative humidity, air velocity, ventilation rate, carbon dioxide (CO_2) and ozone (O_3) concentration were measured during each exposure. Paired t-tests and Wilcoxon's matched-pairs signed-ranks tests were carried out to observe whether the exposure conditions influenced perceived air quality, intensity of SBS symptoms and performance.

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RESULTS

Measurements showed that the conditions in the "field laboratory" during exposures were close to the intended levels: operative temperature was on average 22.2 °C (±0.2), the relative humidity was 30 % (±1), the ventilation rate was 9.5 l/s per person and the air velocity was <0.10 m/s. Sensory evaluations showed that the proportion dissatisfied with the air quality was significantly higher when the pollution source was present in the office (Figure 2); ca. 1 % were dissatisfied with the air quality outdoors.

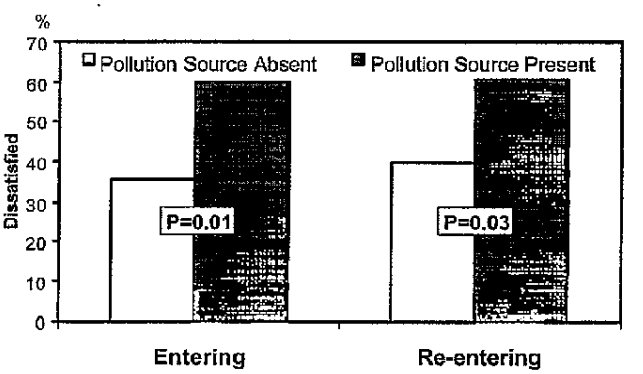

Figure 2. Percentage dissatisfied with the air quality upon entering and re-entering the office as a function of presence or absence of the pollution source

The intensity of "dizziness" and "difficulty in thinking clearly" was significantly higher in the office with pollution source present (Figure 3), while the intensity of other SBS symptoms was not significantly associated with the office either with or without the pollution source.

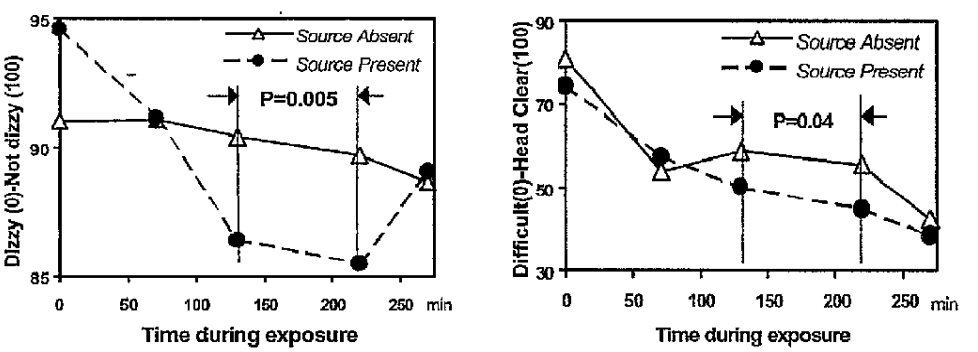

Figure 3 "Dizziness" (left) "Difficulty in thinking clearly" (right) as a function of time during exposure in the field laboratory

The performance of text typing and addition was significantly lower when the pollution source was present (Figure 4); performance of proof-reading was also negatively affected by the presence of the pollution source, but the difference between conditions did not reach

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significance. The significant differences in performance were observed only at the time when the intensity of the SBS symptoms was more severe.

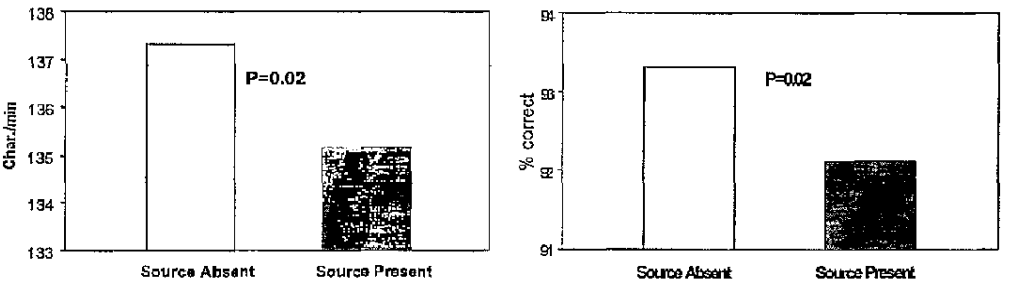

Figure 4 Speed of text typing (left) and accuracy of adding (right), as a function of the presence or absence of the pollution source in the office.

DISCUSSION

The significant results of the present study are in line with the original study by Wargocki et al. [1], and thus support their findings. They also show that the new Swedish "field laboratory" operates as intended, i.e. the environmental conditions can be kept constant with satisfactory accuracy.

The observed difference in perceived air quality indicates that a rather moderate change in air pollution could give more dissatisfaction. The increased indoor air pollution caused also some SBS symptoms. This, together with the effects on perceived air quality, may contribute to the observed differences in performance on office tasks requiring concentration.

Small changes of the methodology were made before carrying out this study, compared to the study of Wargocki et al. [1]. An open-ended task (creative thinking) and a proof-reading task were used instead of the performance assessment battery and knowledge and recall test. The duration of the tasks was also slightly altered to suit the new experimental plan.

CONCLUSIONS

- The results imply that increased air pollution negatively affects the perceived air quality, SBS symptoms and performance of typical office tasks. These results support the earlier similar findings of the study by Wargocki et al. [1] in which similar procedures and the same pollution source were used.
- Results of the present study show that the office used as the new field laboratory works reliably.

ACKNOWLEDGEMENTS

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